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SYNCHRONIZATION OF DECISION FEEDBACK SATELLITE TELEMETRY SYSTEMS

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Re: Contract No. NAS 5-408

Subject: Synchronization of Decision Feedback Satellite Telemetry Systems

A bstract

Summary

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This memorandum is an adjunct to Memorandum No. 6 which discusses the advantages of feedback telemetry systems over unidirectional telemetry systems. The type of feedback system considered here is one where the receiving site commands the bird to repeat those portions of the transmission which are deeply embedded in the system noise. Various ways of synchronizing the feedback and direct channels are considered so that the proper portion of the message is repeated and the receiver can identify the repeated material.

Discussion

A satellite decision feedback system is one where the ground site decides on the acceptability of the received telemetry signal and then commands, via a ground-to-vehicle link, the vehicle to continue sending new data or to repeat the data in whole or in part. There are two ways the ground site can decide on the acceptability of the received signal. The first consists in using error detecting codes. The second consists of monitoring the signal itself, for example by monitoring signal-to-noise ratio.

The simplest decision feedback system is a discarding system. In this case the information contained in the received ambiguous portions of the transmission are discarded and a fresh decision is made on each repeat.

Example: Consider a very simple PCM feedback telemetry system for a near range satellite. In this simple system each digit is sent by phase modulating a carrier.

However, to avoid having to synchronize the decoding of the digits, a digit is sent by sending a burst of an in-phase or out-of-phase carrier, the burst being preceeded and followed by a no-transmission period. Suppose, for example, the digit duration is one millisecond and the space intervals are also one millisecond. For an accuracy of one percent, where seven digit words are required, the data rate is one sample per fourteen milliseconds.

Consider now the satellite being only 100 miles above the ground site. In this case the propagation time between the bird and the ground is about a half millisecond. This means that there is sufficient time for the ground site to receive a digit, decide if it is acceptable, and transmit this decision back to the bird before the bird sends the next digit. In this case the decision can be made on a digit-by-digit basis (each digit accepted or rejected depending upon whether or not it falls within the null zone) and the repeated digit will immediately follow the request.

The above system operates well because the propagation time is less than half the duration of the digits. To use such a system at distances of 1,000 miles would require that the digits be 5 milliseconds long and the data rate be only one sample per 70 milliseconds. This is quite a low data rate. There are two alternatives.

1. The first alternative is based on the observation that the data rate is very low and hence the bandwidth is low. In this case frequency multiplexing as well as time multiplexing can be used. Thus several telemetry signals can be sent on several different frequency channels.

<u>Example:</u> Consider a satellite 1000 miles above the ground site. The telemetry system consists of ten frequency multiplexed channels, each channel being similar to the previously described one, except the digit duration is ten times as long and the power during transmission of a burst is ten times as much. The factor ten

is arrived at here by multiplying by $(10)^2$ to account for the ten-fold increase in range and then dividing by 10 to account for the ten-fold increase in pulse duration. The received energy per digit thus remains the same and hence the reliability is the same. Moreover, the ten-fold increase in digit duration is compensated by having ten channels for the same overall bandwidth. Thus the data rate is the same. The advantage of this system is that, as in Example I, decision feedback can be applied on a digit-by-digit basis.

2. The second alternative is based on using decision feedback over several digits.

Example: Suppose to the seven digits of each word a parity check is added. This extra digit permits single error detecting. If each digit has a one millisecond delay, plus an additional millisecond inter-digit interval, then each word takes 16 milliseconds. This allows up to 8 milliseconds for one-way delay for the feedback signal. When allowances are made for processing time and the like, a realistic maximum range is 20,000 miles.

In operation the ground site sends a repeat, if required, as soon as possible. When the satellite receives the repeat it will be at that instant in the middle of a word. The next word transmitted should be a repeat of the previous word. Note that a buffer storage will be required if the original signal or the tape cannot be interrupted to send the repeat.

Suppose the time delay of the transmitted signal exceeds a word, and the range is unknown. Then the receiver cannot tell which word is to be repeated unless feedback synchronization pulses are used. Rather than introduce additional synchronization pulses the frame marker pulses can be used. In this case when a repeat is requested the order of word in the frame is indicated as well.

Example: Consider 8 digit words (seven digits plus parity check) being sent using a one millisecond digit duration followed by a one millisecond inter-digit duration.

If a frame consists of twenty words each frame is about 320 milliseconds long. Thus time delays up to somewhat less than 160 milliseconds can be tolerated, or the range can be as great as 800,000 miles.

For still greater ranges the frame synchronizing pulses can be coded to indicate the order of the frame.

Example: If alternate frame sync pulses are distinguishable, ranges up to 1.6 megamiles can be handled. If there are four distinct frame sync pulses, ranges up to 3.2 megamiles can be handled and so on.

If desired the particular word in error within the frame can be repeated. A better method, which avoids upsetting the synchronization of the system, is to repeat the whole frame. This will not greatly lower the information rate, as might be expected, because when a drop-out occurs large portions of a frame will be obliterated. In this case the decision to repeat a frame could be based on several words within the frame being incorrect, or overall frame parity check digits, or monitoring the signal-to-noise ratio.

The above examples represent feedback synchronization systems which are useful both for satellites and for space probes. For a satellite which is in orbit, one can base the feedback synchronization on the minimum and maximum transmission times.

Example: Consider the case of a satellite in a circular orbit. During an orbital pass, the range from the satellite to the ground site varies thereby causing a variable delay time. The minimum delay occurs when the satellite is at the zenith and the corresponding delay is determined by its altitude. This minimum delay imposes no restrictions on the minimum pulse length. For example, if the minimum delay is 2 digit durations, the system can be designed such that a request for a repeat refers to two digits back. However, as the range increases such that the delay approaches 3 digit durations, the system will fail to repeat the proper digit.

Hence the maximum change of delay is of interest.

The maximum delay exists when the satellite first appears over the horizon. It is readily shown that

$$(R + h)^2 = L^2 + R^2 \qquad (1)$$

where

R = radius of the earth

h = satellite altitude

L = maximum range from ground site to satellite.

The maximum change of range ΔL is simply L-h. Dividing ΔL by the speed of light and substituting the appropriate values yields

$$\frac{\Delta L}{C} = \Delta T_d = \frac{h}{186} \left[\left(1 + \frac{7927}{h}\right)^{1/2} - 1\right] \qquad (2)$$

where ΔT_d is the maximum change of delay time in milliseconds for a given satellite altitude h in miles. Equation 2 is plotted in Fig. 1. Since the maximum change of delay is bounded, it is feasible to communicate with orbiting satellites at any altitude with decision feedback.

What these examples indicate is that there are many ways to solve the feedback synchronization problems. The best one to use depends on the range, the data rate, and the signal-to-noise ratio of the system.

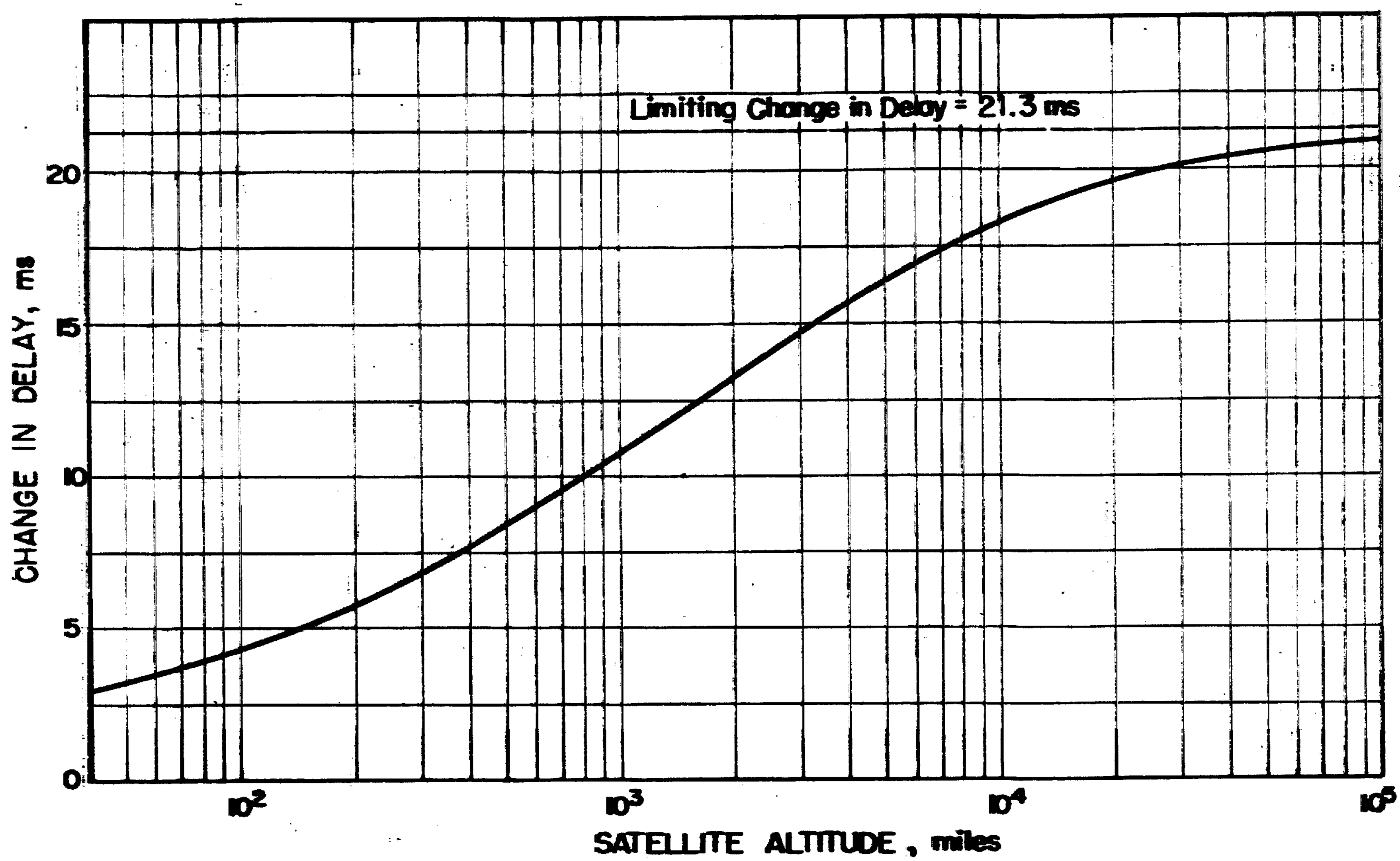

Fig. 1

Maximum Change of Delay Time vs Altitude for Orbiting Vehicles

(Circular Orbits Assumed)